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Analysis

Concepts Fostering Resource Efficiency: A Trade-off Between Ambitions and Viability☆

Arnold Tukker[a,b,*], Paul Ekins[c]

[a] Leiden University, Institute of Environmental Sciences (CML), Leiden, Netherlands
[b] Netherlands Organisation for Applied Scientific Research TNO, Delft, Netherlands
[c] University College London, Institute for Sustainable Resources, London, UK

ABSTRACT

There is no shortage of concepts that aim to show how our economy can become more resource- efficient such as eco-innovation, cradle to cradle. We analysed a long list of concepts using three dimensions: scope of change, ambition with regard to the (paradigmatic) degree of change, and the existence of plausible drivers and pathways of change. Reviewed literature on governance and transitions suggests that the more extensive and radical the scope and ambition of change are, the higher systemic and institutional resistance to change will be. From roughly 30 concepts reviewed, none gave a credible answer on how to overcome this dilemma. Resource scarcity is not (yet) a clear driver for change. Where in the field of climate change policy starts to respond to compelling scientific evidence of danger, in the field of resources only win-win policies are seriously considered. Advocates of radical resource efficiency must find credible pathways that allow it to be pursued at scale in practice or hope that incremental change will open up space for more radical options, in order to avoid the significant economic and social disruption from supply-demand imbalances that some now fear.

1. Introduction

In the last decade, resource efficiency and the related ambition of creating a circular economy has become a prominent topic on the sustainability agendas of particularly the EU (EC, 2014a), China (State Council, 2013) and Japan (MoE, 2006). More recently, this agenda received support from important societal stakeholders, such as the Ellen MacArthur Foundation (EMF, 2012, 2015) and the World Economic Forum (WEF, 2014). The ambition and scope of such a resource-efficiency and circularity agenda can be defined in different ways. Some interpretations of resource-efficiency go as far as to include the ability of nature to absorb pollution and waste, expanding this agenda to a wide range of environmental problems (EC, 2005). For the purpose of this paper, we focus on the efficient use of resources per se. We include both biotic and abiotic resources (cf. EMF, 2012). In this context, resource efficiency is usually defined as the useful material output related to (life cycle) material input (e.g. Dahlstrom and Ekins, 2005), or the monetary value of product/service output related to (life cycle) material input (e.g. EC, 2014a). While the planetary boundaries for resource extraction still need refinement (cf Rockström et al., 2009; Steffen et al., 2015), authors such as EMF (2012) and UNEP (2011) suggest that drastic improvements in resource efficiency are required to enable future economic growth, and/or that absolute reductions of resource use should be pursued. EMF (2012, 2015) calls this a 'resource revolution'.

In the last decades, many concepts in the field of sustainability have been proposed that (amongst others) aim to show how economies can become more resource-efficient. Examples include industrial ecology, eco-innovation, cradle to cradle, transition management, beyond GDP, eco-efficiency, and a couple of dozen others. Some of these concepts, especially the more radical ones such as de-growth, go beyond resource efficiency in their scale of envisaged change, but for all of them increased resource efficiency is a major objective, and therefore the term is used in this paper to include these concepts as well. One concept, which is more or less synonymous with resource efficiency, is decoupling, which, in the formulation of UNEP (2011, 2014a) signifies that resource use and/or environmental impacts are increasing less fast than GDP (relative decoupling) or actually declining while GDP continues to grow (absolute decoupling). It can be seen that decoupling is a necessary characteristic of increased resourced efficiency as defined in the previous paragraph, so that in the categorisation that follows increased resource efficiency and decoupling are treated together.

This paper evaluates the potential of these concepts to guide how to achieve radical resource-efficiency improvements. For this, the concept

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* Corresponding author.
E-mail address: tukker@cml.leidenuniv.nl (A. Tukker).

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must address broad areas of society, be radical in nature, but, most importantly, also offer clear guidance as to how incentives for change can be implemented. Yet, as will be seen, the literature on governance and transitions suggests that the more extensive and radical the scope and ambition of change are, the greater will be the systemic and institutional resistance to change. The evaluation is done via the following steps:

- Section 2 analyses as background how the literature discusses how momentum for change towards resource-efficiency may be brought about
- Section 3 reviews a number of existing classifications of concepts related to eco-efficiency, sustainability and resource efficiency (including these terms themselves), and derives the analytical framework used in this paper
- Section 4 scores some 30 concepts on the dimensions of this framework
- Section 5 provides a discussion and conclusions.

2. Changes to Circularity and Resource Efficiency – What Factors Create Momentum?

2.1. Factors Creating Resistance to Change

Changes to resource efficiency and circularity require incentives for the change to take place. Scholars in the field of innovation and transition management in this context commonly make a distinction between incremental changes and radical changes. Incremental changes usually marginally affect the overall system and are related to relatively limited gains. The potential for cost reduction by using resources more efficiently often is the main driver. Such changes however are unlikely to create radical reductions of resource use in society, nor bring about the overall transition to a circular economy.

The theory of transition management offers a helpful perspective to understand what helps and hinders more radical change processes in society, such as a radical improvement of resource efficiency and the transition to a circular economy (see e.g. the contributions in Elzen et al., 2004; see also Geels, 2002, 2005 and Kemp, 2008). Such transition processes can be evolutionary, where the outcome is not planned in a significant way, or co-evolutionary and goal-oriented, where some vision of the end-state is guiding decision makers or orienting strategic decisions. Most authors analyzing such transition processes propose to use a multi-level, multi-actor, and multi-phase concept to describe the process of change or transition (e.g. Rotmans et al., 2001; Elzen et al., 2004; Geels, 2005; Kemp et al., 2007; Loorbach, 2014).

The multi-level concept divides societal systems in three main levels.

- a macro- or landscape level, which is to be taken for granted on short- and medium term. It contains very or fairly stable factors such as geopolitical realities, widely held values, and stable megatrends (e.g. in the area of demography). It poses boundary conditions for the next level (the regime) to evolve, and is hence normally a source of stability (with the exceptions when disruptive shocks at this level occur, such as wars and natural disasters)
- a regime level. The regime itself is an interdependent and co-evolving set of technologies, symbolic meanings, services, consumer practices, rules, financial relations and expectations. It is difficult to change one part without the rest. This dynamic equilibrium changes usually only incrementally. A simple example: you cannot put a hydrogen car on the road without hydrogen gas stations, new safety rules, maybe even new driving licence standards, etc.
- niches, where innovators can try out new consumption and production practices. It is however often difficult for niches to become mainstream, due to the stabilizing effects at regime and landscape level.

The multi-actor concept metaphorically points at the fact that systems have to be seen as socio-technical regimes: interrelations of existing technologies, knowledge, skill sets, routines, regulatory demands, policy preferences, available infrastructures, and prevailing cultural and symbolic meanings that usually cannot be changed independently, but must co-evolve.

The multi-phase concept stipulates that transitions go through distinct phases: a pre-development phase in which new practices are tested in niches, a take-off phase in which elements of the new regime challenge the old regime and start to break through, a (relatively short) acceleration phase in which the old regime starts to break down, and a stabilization phase in which the new regime has taken over. The take-off phase is crucial for the success of the transition or regime change, and needs a ‘green light’ at all levels: availability of promising elements of a new regime in niches, instability in the existing regime, and a growing incompatibility between regime and landscape.

Transition theory explains why intentional radical socio-technical change is so difficult. Both the landscape and regime levels guide developments. This dynamic equilibrium changes usually only incrementally. But the theory can also help to find tensions or ‘cracks’ in the system that can make stimulating changes easier. Such ‘cracks’ can be: internal tensions in the production-consumption regime, or misfit between regime and landscape, and can have a normative and operational dimension. Examples include a production structure evidently based on labor exploitations in the South (misfit with ethical meta-values), or a sector practising agriculture in greenhouses, that due to rising energy prices becomes too expensive (operational misfit).

When promising niches are available that have matured (deepened) and got connected (broadened), and at the same time ‘cracks’ develop or ‘shocks’ in the landscape occur, pressure on the regime may become so high that rapid change may become possible (niches ‘scaling up’). The regime breaks down, and niches plus the remnants of the existing regime will develop new structures, which eventually will stabilise and form a new regime (cf. Geels, 2005; Kemp and van den Bosch, 2006).

2.2. Options for Intentionally Guiding Change

We can roughly identify three approaches by which transitions can be stimulated – in our case the one to a resource efficient economy.[1]

First, one can rely largely on market based instruments. The World Business Council for Sustainable Development (WBCSD), probably the most powerful and influential industry think tank on sustainability, even has a slogan that reflects this: ‘Sustainability through the market’ (WBCSD, 1999). The idea is that once perverse subsidies are abolished and the undesirable side-effects of our current production and consumption systems are internalized into the market prices, the market mechanisms will direct innovations in the correct, sustainable direction. This approach, using mainly market-based instruments is useful if one knows which changes to the market incentive system will change the behaviour of actors in the direction of more sustainability. The exact means or roadmap to the sustainability goal can in principle still be uncertain. This approach has the following limitations:

- Since this option implies that changes in the rules of the (market) game must be implemented, most importantly internalizing external costs, a party must have the power or legitimacy to make them.
- If there are strong impediments to change that cannot be overcome by financial incentives, this approach will not be effective.

The second approach relies heavily on top-down government. This type of approach to transition management is probably supported by

[1] As discussed by Tukker and Butter (2007), these approaches reflect the so-called individualist, hierarchist and egalitarian perspectives in Cultural Theory, see e.g. Thompson et al. (1990), and further discussion in Tukker et al., 2013

those who call for a 'master plan' or 'Apollo-program' for saving the environment. It should consist of an all-encompassing effort with a lead role for the government in various fields to realize the necessary system innovations. In more moderate forms, the goals and planning are more indicative and the assessment of which means to use more participatory, but there is still a powerful central actor which can when necessary enforce progress of the process of change. The US space program launched by President Kennedy is one example. And though at terrible human costs, both the Soviet Union and China transformed themselves from mainly agricultural countries into industrial nations via a number of strong centrally organized 5-year plans, changing the structure and culture of their society in the process (Kennedy, 1988). This approach can be applied under the following conditions.

- First, there must be a party in the system that has the power or legitimacy to apply a hierarchist governance model.
- Second, it must be fairly clear which transition goals must be reached and which means are the most appropriate to do so. Under these conditions, a top-down planning approach can be an effective and efficient way to realize a transition.

The third approach relies more on bottom-up activities in society of front-runner companies, civil society, and progressive governments. Scholars representing this view try to understand how fundamental change can be fostered via 'radical incrementalism', 'variety and selection', 'connecting long term visions and goals to short-term implementation activities', and fostering 'coalitions of the willing' (e.g., Ostrom, 1990; Rotmans et al., 2001; Hajer, 2011). The idea is that bottom-up initiatives will experiment with socio-technical innovations in a domain where a transition is desired, creating niches of change. Over time, this may lead to a situation where niches are capable to outcompete mainstream systems via the market based mechanisms of the first approach, or that gradually more critical mass for policy support for change is created, which then allows to apply the more top-down approaches from the second approach (Tukker and Butter, 2007). Noteworthy initiatives include the World Economic Forum, with various agenda councils related to climate change, water and urban sustainability, the Global Compact, and initiatives such as Transition Towns and the Dutch action organisation Urgenda. The real question is how these largely bottom-up initiatives can ultimately be channeled and consolidated into lasting change. Otherwise, these noteworthy initiatives will end up being little more than repetitive meetings where good ideas are presented, ideas that, in the absence of institutional adjustments, cannot compete with the mainstream way of doing things and, hence, remain in their niches.[2]

2.3. Reflection: Can a Resource Revolution be Realized Without Absolute Scarcity as an Incentive?

Section 2.2 indicates that creating a trajectory of radical change to a resource-efficient society is no easy matter. Market-based and top-down approaches both require a government that is legitimized to enforce change – either in the form of creating market-based instruments and incentives or regulation. Bottom-up initiatives either must become winners in a market via a more or less autonomous innovation process, or at some point get enough policy support to enforce implementation, to avoid dying out in their niches. Creating such levels of policy support is difficult and time consuming – interests diverge (Nelkin, 1984), beliefs about what is desirable or not differ (Sabatier, 1987), and some discourses are more dominant than others (Hajer, 2005). Powers between actor coalitions that represent these interests, beliefs and discourses are unevenly distributed (Sabatier and Jenkins-Smith, 1993). All this hampers sustainability transitions in general, including that to a radically more resource efficient society. In the resources domain, the case for resource efficiency is still mainly made to point at possible economic win-wins (saving resources saves money), or that resource-efficiency and circularity are an answer to resource scarcity and price volatility of resources (e.g. EMF, 2012; Bastein et al., 2013; WBCSD, 2016).

It is however questionable whether the resource scarcity argument will drive a radical change to resource-efficiency in the near future.[3] Table 1, based on an evaluation of Tukker (2013), suggests the following:

a) Fossil energy materials. Given the climate challenge there is in principle a need for a radical reduction in their use, or, rather, the impacts of their use, with around a factor 10 reduction in carbon emissions required by 2050. This radical reduction however will only take place if enough political will materialises to really embark on strong and radical climate policies (IEA, 2016; Shell, 2016). Even despite the COP21 in Paris it is questionable if this will happen. It is further unlikely that absolute scarcity of fossil energy will become a bottleneck in the next few decades, significant amounts of coal, oil and (shale) gas being still available (McGlade and Ekins, 2015).
b) Building and construction materials. Apart from materials that during their production create significant emissions of carbon (e.g. cement, steel, aluminium), there is no clear sign that resource or emission constraints will lead to a need to limit their use. Localised problems in e.g. densely populated areas apart, they are abundant.[4] Any pressure on the use of materials such as cement, steel and aluminium seems most likely to come from climate policies, rather than from a greater desire for resource efficiency.
c) Metal ores and industrial minerals. Here we encounter a very mixed situation, where some materials may indeed see absolute scarcity in the next decades, but where in most cases supply disruptions are caused by geopolitical factors or market instabilities rather than real scarcity.[5] In such cases, simply learning better how to manage a market characterised by uncertainties in future demand and long lead times for opening mines, and dealing with geopolitical factors, can reduce many of the problems that exist today.
d) Biotic materials, in relation to land and water use. The extraction of biotic materials is mainly limited by water and land use constraints

[2] Even those who claim that we should build less on top-down agreements and foster and trust the 'energetic society' more (Hajer, 2011) acknowledge that there is a role for authorities: 'Authorities should give clarity (..). Then investors will dare to invest. Offer them certainty. Create new green accounting rules. Abolish subsidies that prevent innovation and keep us in the 20th century'. Maarten Hajer, column based on a presentation during the meeting 'Rio aan de Maas' (Rio on the Meuse'), 'Rio as global fair', 30 May 2012, as published on http://www.pbl.nl/node/55684 (accessed 14 August 2012).

[3] One reviewer suggested that impacts of resource use would create the driver for radical changes to resource efficiency. We question this argument. In Europe for instance, resource use has grown significantly in the last decades, while apart from carbon emissions most environmental pressures were reduced (EEA, 2015). Even in cases where higher resource use almost inevitably leads to higher environmental pressures, such as in the case of climate change in relation to fossil fuel use, policy legitimation and action took decades to develop. It is hence questionable that pointing at the impacts of resource use will provide sufficient policy legitimation to embark on a resource efficiency policy that is radical and may hurt interests of the current mainstream actors.

[4] But see UNEP, 2014b for early signs that sand may be starting to be scarce in some places.

[5] A clear example of this is provided by Rare Earth Elements. In 2002 low prices of Chinese mines next to environmental problems led to closure of the only Western mine left, the US Mountain Pass mine, that had dominated supply for decades. The total value of REE materials mined annually was < 1 billion US$ at the time. Although demand was expected to rise, the level to which was uncertain, and the (minor) mining companies in the West simply could not take the risk nor attract the capital to anticipate this new demand by opening new mines. Around 2007, China foresaw that it needed most of the nationally mined REE for its own industry, and started to reduce exports which led subsequently to a supply crisis in the West – high price volatility, price hikes, etc. Only then the West scrambled to see if new mines could be opened on the shortest possible notice – which given the long lead time to open mines would still take years. Given the fact that proven reserves of REE that can be mined economically are 800 times annual use, this crisis clearly has nothing to do with scarcity (Tukker, 2014).

Table 1
Potential resource constraints by material category usually discerned in economy wide Material Flow Analysis (elaborated from Tukker, 2013).

Type of resource	Fraction of global resource extraction	Basis for planetary limits	Potential limit	Reference
Fossil fuels	20%	Absolute scarcity CO_2 emission targets	EU greenhouse gas (GHG) targets (20-20-20 or 30% reduction by 2020) Scientific targets (> 80% reduction by 2050)	IPCC (2007, 2013), Meinshausen et al. (2009).
Metal ores and industrial minerals	10%	Absolute scarcity (varies by metal). Most metal ores need high levels of energy to be transformed, implying a 'linkage' to CO_2 emission targets and energy constraints	Focus on 14 critical raw materials identified in the Raw Materials Initiative. Changes in energy and mobility infrastructure (solar cells, batteries) determine future criticality	EC (2014b). For linkages with energy use, see Graedel and Van der Voet (2010).
Non-metallic minerals (mainly building materials)	40%	With the possible exception of sand, absolute scarcity seems irrelevant, except in densely populated areas where space for mining for these minerals is limited.	Implicit targets for non-metallic minerals that need high levels of energy in their production (e.g., cement, ceramics) and linkages to land use targets (e.g. soil sealing)	For linkages: e.g. Hanle et al. (2006)
Biomass, in relation to land and water use	30%	Maximum human appropriation of net primary production of biomass (HANPP), the available bioproductive land taking into account reservation for nature areas, and the renewable supply of water by region	Currently, 30%–35% of available biomass is extracted by humans. Target may be stabilization or minor growth. As for land use which is dominated by agriculture, there is conflicting information whether efficiency growth in agriculture will avoid land shortage in future. For water, a global 'water gap' of 30% is expected in 2030	Vitousek et al. (1986), Haberl et al. (2007), Erb et al. (2009) OECD/FAO (2009) Nature (2010); Hoekstra and Chapagain (2007) Water resources group/McKinsey (2009).

in relation to biodiversity impacts. Population growth, diet changes and the use of biofuels all are likely to lead to the need for a higher production of biomass in future. Without efficiency improvements, this will lead to pressure on land use, biodiversity loss, and a water shortage of 30% by 2030 (e.g. Water Resources Group, 2009; Nature, 2010). These sources however also suggest such problems can be overcome by a Factor 2 improvement of land and water-efficiency by 2050, or 2% per year. While this certainly is a challenge, it is probably one that can be realized by incremental rather than radical innovations and changes.

Although there are obviously linkages between these resource categories, such as that a more productive agriculture may require more energy input (Graedel and van der Voet, 2010), the overall picture is that in the next decades scarcity will not be a transition driver. Yet, since transitions take a long time, and resources on Earth are indeed finite and may become scarce in the long term, it may be useful to start working immediately on a transition to radically more efficient resource use and a circular economy. A key question, however, is how to do this when for many resources there seems still ample scope to enhance production, and a critical mass and legitimation of government for interventions other than in support of cost reduction and enhanced competitiveness is lacking.

3. Dimensions for Analyzing Sustainability and Resource-Efficiency Concepts

3.1. Introduction

In the past, various authors have reviewed strategies that can guide a transition of our economic system of production and consumption towards a higher level of eco-efficiency, resource efficiency and/or sustainability. In doing so, they have proposed various key dimensions that can characterize such strategies. This section reviews a number of such classifications, most notably from the EU Eco-Innovation Observatory (Eco-Innovation Observatory, 2013), the OECD's work on eco-innovation (OECD, 2009), work of GWS on 'Green growth' strategies (GWS, 2013) and others (Hopwood et al., 2005; Tukker and Tischner, 2006). In this analysis, we did not strive for a comprehensive review of all classifications that may have been developed in the past. We did however use the classifications that have been developed under assignments of dominant policy actors, such as the German government, the EU and the OECD, which we think is an appropriate sample to build our own classification upon. We review these classifications in Section 3.2 and on this basis, develop our own classification in Section 3.3.

3.2. Dimensions Used in Earlier Studies

The first conceptualization we show is one developed by the European Eco-Innovation Observatory (2013). They use this to classify eco-innovation concepts such as industrial symbiosis, product improvements, and extended producer responsibility. This conceptualisation discerns two dimensions: the degree of change (system adaptation, or systems transformation), and the scope of the system that is changed (system components such as individual technologies or products; sub-systems such as value chains; or transformations of major parts of society, such as the energy system, the urban system). This then leads to a classification as in Fig. 1, discerning four quadrants: incremental innovation, radical change, system adaptation and transformative system innovation.

A second classification of eco-innovations is given by the OECD (2009) in its Sustainable Manufacturing and Eco-Innovation Synthesis Report (see Fig. 2). The x-axis resembles very much a parameter that is also used by the EU Eco-innovation observatory: modification of existing systems or creation of fully new systems. The y-axis however

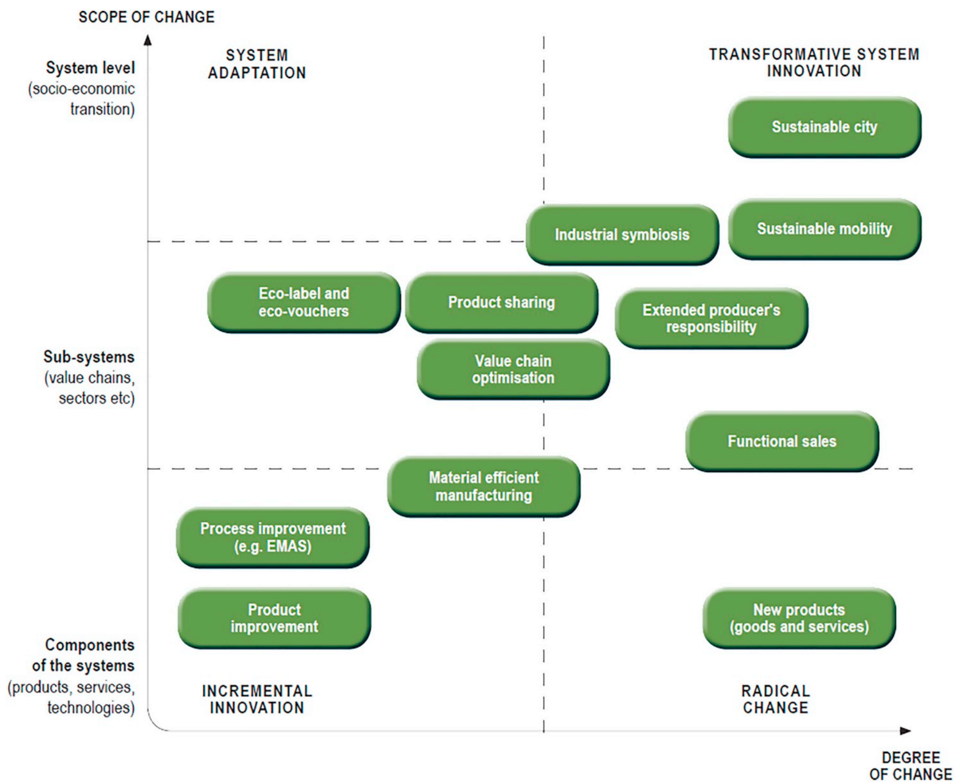

Fig. 1. Classification of eco-innovations from the EU Eco-innovation observatory; Annual Report 2012, January 2013, Fig. 4.4, p.37 (see: http://www.eco-innovation.eu/index.php?option=com_content&view=article&id=629:europe-in-transition&catid=80:annual-reports&Itemid=293, accessed 25 May 2017).

looks at elements of the system that is targeted, rather than the scope of change of the system: products and processes, organisation and marketing methods, or institutions. The OECD uses this to identify if change is mainly of a technical or non-technical nature. (See Fig. 3.)

Lombardi et al. (2011) use a classification of Hopwood et al. (2005) to organise various views on sustainable development. Again, the x-axis gives the level of transformation required, but focuses on the environmental aspect of sustainability only. The y-axis covers the level of importance given to human well-being and equality, and is hence clearly of a socio-economic nature.

Tukker and Tischner (2006) identify five main intervention points along the production-consumption chain that each can improve the environmental performance of our economic system. In short it concerns (cf Tukker et al., 2010)

- 1: End of pipe/reducing emission factors
- 2a: Enhancing productivity of existing systems - greening production processes and products 2b: Enhancing productivity via system innovations – similar to 2a, but creating ‘Factor X’ improvements via system innovation of products and processes;
- 3: Intensifying the use of products, e.g. via product-service systems
- 4: Enhancing immaterial consumption/less impact intensive expenditure;
- 5: Enhancing quality of life without additional expenditure.

These improvement strategies now can be plotted on two axes: whether they address production or consumption and whether they are radical or incremental (see Fig. 4).

Finally, GWS (2013) developed a classification of about two dozen ‘Green Growth’ strategies. They used about 16 guiding questions related to (a) environmental, economic and social impacts, (b) possible structural economic change, (c) underestimated future welfare impacts and

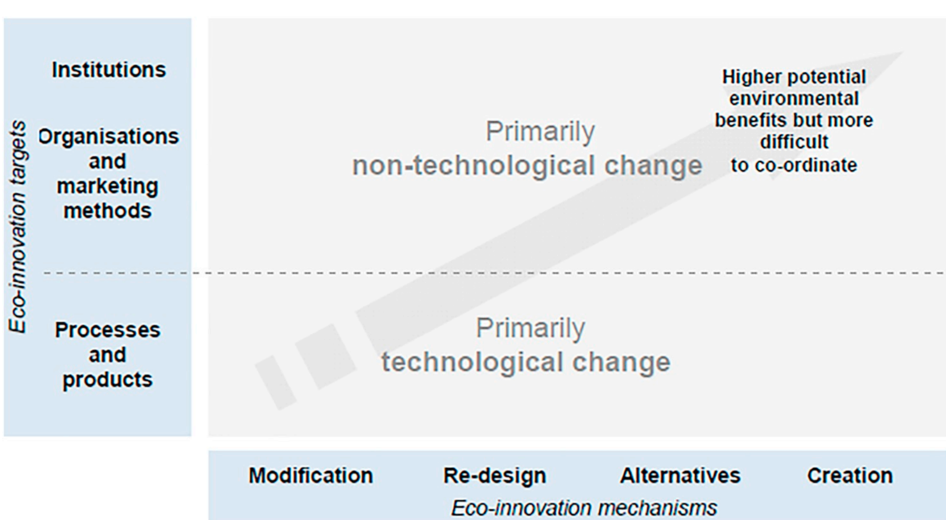

Fig. 2. A typology of Eco-innovations (Fig. 4, p.13, OECD, 2009)

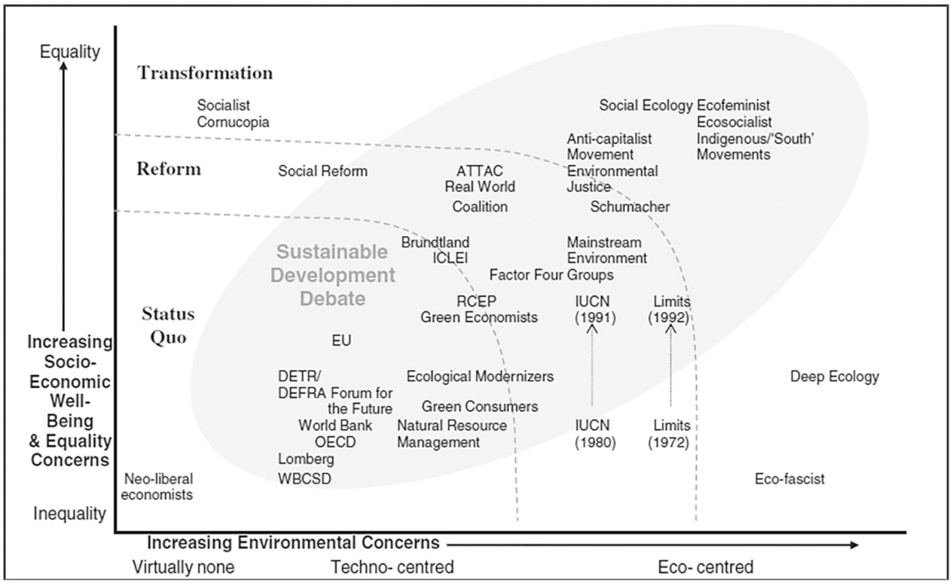

Fig. 3. Mapping of views on sustainable development from Hopwood et al. (2005), Fig. 1, p.41.

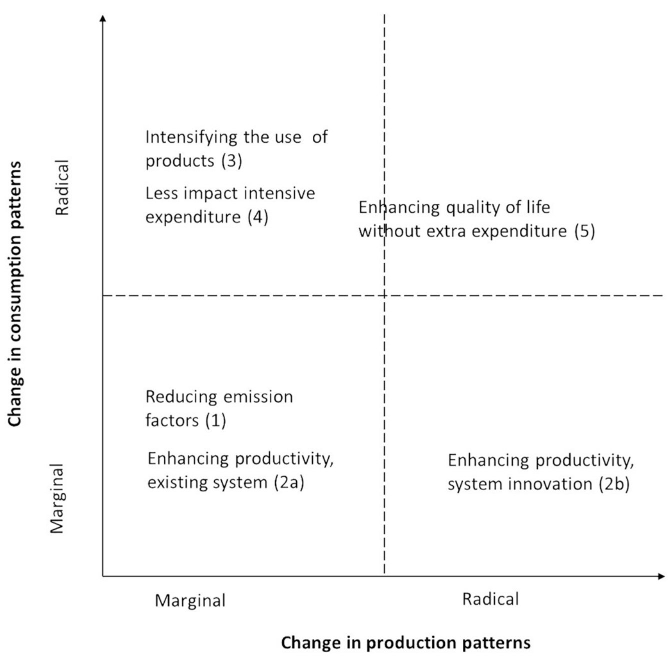

Fig. 4. Level of change in production and consumption patterns in relation to different decoupling strategies (Tukker and Tischner, 2006).

(d) supportive institutional foundations and political constellations. The answers on these questions allowed them to map each concept in a three dimensional framework that discerns an economic, environmental, and social axis, reflecting the extent to which each concept emphasises economic growth, the viability of ecosystems, and the social quality of societies.

3.3. Evaluation Dimensions Used in this Paper

When comparing the evaluative frameworks discussed in the former section, the following can be observed. The Eco-Innovation Observatory uses as dimensions the Scope of change (system components or systems) and the Degree of change (in terms of incremental and radical). The OECD again uses Scope of change but then different system elements as targets. Tukker and Tischner also use the Scope of change as parameter, distinguishing between production and consumption, next to the Degree of change (incremental and radical). Hopwood et al. use a social and environmental dimension in combination with Degree of change. The GWS classification is somewhat more complex, with the Degree of change along each of the environmental, social and economic dimensions.

As the GWS study indicates it is not difficult to end up with dozens of criteria in respect of which new concepts with regard to resource efficiency can be evaluated. A drawback of using many criteria is that one easily loses oversight. We hence prefer to reduce the number of criteria or parameters to a maximum of three. On the basis of the above we decided that for the analysis in this paper at least the following dimensions are relevant, and propose to use a 3-point scale to define positions on these dimensions:

- Scope of change

This plays a role in virtually all classification systems discussed in Section 3.2, and seems also relevant given the long list of concepts mentioned in the introduction. Some concepts focus on parts of the value chain, such as responsible mining. Others aim at transforming whole systems. We propose to classify initiatives in one of the following three categories, which we will later use as ranked levels in the evaluation:

- Scope is a specific industry sector (e.g. mining)
- Scope is a value chain
- Scope is societal system or large (sub)-systems thereof (e.g. food, energy, mobility)

- Ambition with regard to the (paradigmatic) degree of change

This resembles the degree of change found in many of the classification systems listed above, but deliberately adds the adjective 'paradigmatic' to it. Currently the sustainability discussion in general and the resource efficiency discussion in particular is often still framed in the utilitarian, economic rationality that has dominated Western society since enlightenment and the industrial revolution. Many concepts simply still adhere to this existing paradigm. Other concepts however see the existing paradigm as a root cause of the sustainability problem, and hence argue that an upheaval in values, institutions, etc. is essential, towards a direction that some have dubbed a 'Buddhist Economics' that is focused on human development, economic processes at a smaller and more regional scale, etc. (Schumacher, 1973). This goes

Table 2
Classification dimensions and scoring criteria.

	Low (− 1)	Medium (0)	High (+ 1)
Scope of change	One specific industry	Various parts of value chains	Societal (sub) systems
Paradigmatic degree of change	Focus on market-based solutions	Recognition of 'public goods' and related right of government to act in public interest	Seeks an alternative for the utilitarian and rational economic approach to life and nature
Plausibility of pathways of change	Ignores factors making change difficult/does not discuss change	Explains at best conceptually factors supporting change	Explicit and plausible discussion of pathways of change

significantly further than the differentiation between incremental and radical change, which is often just focused on technical aspects. We see further that within the existing paradigm of utilitarian, economic rationality of use of nature there is a differentiation between approaches that emphasise predominantly the business opportunities and benefits for being resource efficient – the role of authorities then simply is to remove market failures - and approaches that see also a threat to public goods – with authorities then having a role of protecting them. This leads then to the following three categories which we will later use as ranked levels in the evaluation:

- No paradigmatic change, focus on market-based solutions
- Intermediate paradigmatic change in the sense that there is a recognition of the 'public good' character of resource-related problems that need government intervention
- Fundamental paradigmatic change, the concept clearly calls for a revolution in our economic system, related values, institutions, etc.

- Explicit Attention to the Plausibility of Pathways of Change

This dimension is in fact fully absent from most of the classifications reviewed in Section 3.2 – only the GWS guiding questions include topics like the potential of institutions and political constellations. Our discussion in chapter 2 shows it is essential to have an understanding how far-reaching, radical changes can be actively fostered. Major historical changes like a 'resource revolution' do not happen automatically. Particularly with regard to radical, paradigmatic changes, Kuhn (1962) already noted that these are not frequent and only happen when the existing paradigm is about to become untenable. Concepts that respond to specified driving forces, or provide a clear pathway or formula as to how change must come about hence have value over concepts that don't. Factors that may help or hinder shaping a 'resource revolution' include a proven (physical or geopolitical) scarcity of resources; technological momentum, social momentum, and institutional momentum. We would propose the following three categories to classify concepts on this dimension which we will later use as ranked levels in the evaluation:

- The concept ignores important factors that make the proposed change difficult or impossible to achieve, or is fully silent on the pathway of change;
- The concept only shows vaguely why change is needed or via what mechanisms it could occur
- The concept is clear in identifying pathways for change

4. Assessment of Sustainability and Resource-Efficiency Concepts

4.1. Materials and Methods

For the purpose of this study, an inventory was made of around 30 widely used sustainability concepts that include a more efficient use of resources in their scope. The ambition was to cover a large sample of widely used concepts, rather than to be fully comprehensive. We based ourselves amongst others on listings in the literature from the former section from which we derived the dimensions on which the concepts should be evaluated (e.g. Hopwood et al., 2005, OECD, 2009 Lombardi et al. (2011), Eco-Innovation Observatory (2013) and GWS (2013)). The list was reviewed and complemented by 5–6 members of the study team from 5 different institutes in 4 different countries. While the final list inevitably is somewhat arbitrary, this procedure ensures it does contain a large number of the most used concepts.

For each concept reviewed, a short literature analysis was done, resulting in a one-to–two- page description of the concept on the following aspects:

1. The concept in brief: main aim, origins/authors, and history/impact
2. Scope of change
3. Ambition of change
4. Pathway of change
5. Actors addressed and if it mainly focuses on environmental, social and/or economic aspects

Each concept was assessed on the three dimensions discussed in the former section: scope of change, paradigmatic degree of change, and plausibility of pathways of change. For this, a simple scoring table was developed as depicted in Table 2, simply using the three levels defined in Section 3.3, giving a − 1 in case of a low score, a 0 in case of a medium score, and a + 1 in case of a high score.

The descriptions are provided as Supplementary information (SI) to this paper. Each description ends with a scoring table in which the cells in Table 2 reflecting the score for the reviewed concept were made grey. For the analysis, the mapping was performed and cross-checked by again the 5–6 aforementioned people in the study team. Differences in opinion on mappings were circulated and discussed in a phone meeting, in which a consensus mapping was reached. One can always debate if such qualitative scoring approaches using expert panels are sufficiently robust. However, it may be noted that the panel used comprised scientists with rather different scientific and cultural backgrounds, and the consensus mapping was concluded without disagreement. While acknowledging that assessment procedures like the one applied always have some residual level of subjectivity, the results are in our view sufficiently robust to be used in the analysis performed.

4.2. Results of the Assessment

The results of the scoring procedure are summarized in Table 3. Of course for realising real radical changes towards for resource-efficiency one would like to see concepts that score high (+ 1) on all aspects. Radical changes towards resource-efficiency must after all

a) Address societal sub-systems rather than single value chains or an individual industry; the volume of change otherwise simply will be too low;
b) Have a high level of paradigmatic degree of change;
c) Have a high plausibility of pathways of change, since otherwise the concept gives no clue as to how change will happen.

Against this background, we presented the results in two other tables, i.e. one that lists all concepts scoring + 1 on paradigmatic degree of change (all but one of which score + 1 on the scope of change as

Table 3
Mapping of concepts.

No		Scope of change	Paradigmatic degree	Plausibility of paths
1	Industrial ecology	1	−1	0
2	Industrial symbiosis	0	−1	0
3	Waste prevention	0	0	1
4	Extended Producer Responsibility (EPR)	0	−1	1
5	Supply chain management	0	−1	1
6	Leasing society	1	1	−1
7	Ecological economics	1	1	0
8	Natural step	1	1	0
9	Weak sustainability	1	−1	1
10	Strong sustainability	1	0	1
11	Small is beautiful	1	1	0
12	Eco innovation	1	0	1
13	Transition management	1	0	0
14	Green growth	1	−1	1
15	Green economy	1	0	1
16	Beyond GDP	1	−1	0
17	Cleaner production	0	−1	1
18	Eco-efficiency	0	−1	1
19	Decoupling/(increased) resource efficiency	0	0	0
20	Pollution prevention pays	0	−1	1
21	Sustainable consumption and production	1	0	0
22	Product service systems	1	1	0
23	Circular economy	1	−1	0
24	3Rs (reduce, re-use, recycle)	1	−1	0
25	De-growth	1	1	0
26	Resilience, safe operating space	1	1	0
27	Hannover principles	−1	1	−1
28	BoP[a] business models	0	−1	0
29	Leapfrogging	0	0	0
30	Slow food, transition towns	1	1	0

[a] Base of the Pyramid (BoP) business models focus on transforming the informal dysfunctional markets, and therefore the whole economic system, of the poorest socio-economic group.

Table 4
Concepts with a high plausibility of pathways of change.

	Scope of change	Paradigmatic degree	Plausibility of paths
Waste prevention	0	0	1
Extended producer responsibility	0	−1	1
Supply chain management	0	−1	1
Weak sustainability	1	−1	1
Strong sustainability	1	0	1
Eco innovation	1	0	1
Green growth	1	−1	1
Green economy	1	0	1
Cleaner production	0	−1	1
Eco-efficiency	0	−1	1
Pollution prevention pays	0	−1	1

well), and one that lists all concepts that score + 1 on plausibility of pathways of change. Tables 3–5 lead to the following, somewhat sobering findings:

a) There is not any concept scoring +1 on all aspects. Or, in other words, there is not any concept that aims at changes at societal level, that is radical and paradigmatic, and that at the same time provides a clear and plausible pathway of change.
b) We see further that by far the most concepts that have a credible/plausible pathway of change in fact do not aim at a high level of paradigmatic change. Indeed, most concepts (extended producer responsibility, supply chain management, green growth, cleaner production, pollution prevention pays and eco-efficiency) simply assume that changes will be driven by win-win concepts, while it is well-known that changes based on such drivers tend to be incremental.
c) Conversely, we see that concepts aiming at a high level of paradigmatic change at best have a conceptual explanation of factors that might bring this change about.

Table 5
Concepts with a high paradigmatic degree of change.

	Scope of change	Paradigmatic degree	Plausibility of paths
Ecological economics	1	1	0
Natural step	1	1	0
Small is beautiful	1	1	0
Product-service systems	1	1	0
De-growth	1	1	0
Resilience, safe operating space	1	1	0
Slow food, transition towns	1	1	0
Leasing society	1	1	−1
Hannover principles	−1	1	−1

It therefore seems that all the concepts analysed in fact just managed to be convincing on one or two of the three aspects relevant for far-reaching change.

4.3. Implications

While as discussed there may be dispute about the individual scores in the tables provided, this overall finding is in fact very much in line with a message system innovation and transition scholars have conveyed for decades. Radical and paradigmatic change implies a shift away from existing socio-economic trajectories, the related infrastructure and sunk costs, routines, and hence also a shift to new parties dominating the system. Resistance to such change is hence significant, as exemplified by e.g. the almost continuous failure of sustainability summits like Rio + 20 (2012), the COPs in Copenhagen (2009), Durban (2011). 'New concepts' like Degrowth, Ecological economics and Small is beautiful hence may point at new ideas for organising society in a sustainable or resource-efficient manner, but simply having an appealing idea – even if embraced by various groups in society - is nothing like sufficient to foster revolutions that can overcome the resisting powers mentioned earlier. This suggests that, in line with insights from the transition management approach, the existing system and parties with power in it must already be under significant pressure before they 'crack' and a real revolution becomes possible.

5. Discussion and Conclusions

This paper evaluated about 30 concepts supportive of the resource efficiency agenda, such as degrowth, the circular economy, green growth, and cleaner production. For each concept our study analysed whether it addressed a small or main part of society, whether the proposed change would be incremental or radical, and whether it provided a credible pathway for pursuing this change. Our research found that concepts either provide

- a vision of far-reaching change, but fail to provide a plausible and credible pathway of how to realise this change, or
- a credible, win-win pathway for change, that upon a closer look is likely to result in incremental change rather than radical change.

This finding is consistent with literature on transitions and system innovations. Radical and paradigmatic changes move away from existing socio-economic regimes and the related infrastructure, sunk costs and routines, and the dominant parties maintaining such regimes. Resistance to far-reaching change is hence usually significant since existing regime players often have no, or a different position in a radically changed future. And, as analysed in chapter 2 (Table 1), autonomous developments are unlikely to force such actors to embark on a 'resource revolution'. Drastic reduction of the use of fossil energy carriers will rely on strong climate policies. To meet the growing need for biomass without a rise of land and water use the challenge is an efficiency improvement of about 2% per year until 2050. For non-metallic minerals and metals the situation is differentiated – if they are on criticality lists, in most cases this is due to supply concentration problems rather than absolute scarcity (EC, 2014b). A business as usual scenario for resource use will have plenty of challenges including balancing resource supply and demand, managing volatility, and managing emission and waste problems related to resource extraction, but it is unclear if this will provide sufficient legitimacy for radical resource reduction policies.

Our contribution is hence mainly that we show all researched concepts fail to provide an answer to this crucial implementation question (or do not need to answer it, since the concept only aims at incremental change), Solid research into via which pathways radical changes to resource-efficiency can be fostered in the absence of scarcity or inherent unbearable pollution as a driving factor is hence essential. Creating yet another appealing concept that fails to explain how to overcome powers that resist radical change is useless.

Of course this is not at all to say that resource efficiency policies are pointless. UNEP (2016, 2017) shows that there are many opportunities for both economic and environmental benefits from the intelligent implementation of such policies. Moreover, resource efficiency policies can complement other environmental policies, such as those that reduce carbon emissions. For instance, UNEP, 2016 (p.33) shows that a strong policy on resource efficiency could reduce global resource use by 17%, and increase global GDP by 1.6%, by 2050 compared to current trends. A combination of a strong climate policy with a strong resource efficiency policy could reduce global carbon emissions by 63% from 2015 levels, and those in G7 countries by 74% from 2015 levels – sufficient to meet the 2 °C global average temperature target endorsed by the Paris Agreement at COP21 in December 2015. It is also uncontested that on the longer term, humanity is probably better off when moving towards a resource-efficient and circular economy. The Earth and its resources are finite. Continuing economic growth on a time span of over a century or more seems only viable by designing societal systems in such a way that resources are kept in closed loops (as long as this does not need significant energy or other resource inputs), or that they are based on massively abundant materials. Furthermore, as discussed the UNEP (2016, 2017) report shows that if policies for radical increases in resource efficiency could be implemented, they would generate greater environmental improvements at lower, and perhaps no, net cost for society as a whole.

The problem lies in the fact that to make this happen without directly present scarcity drivers, on the short term such change becomes a matter of societal and/or political will. The example of the climate issue shows us that such political will, even in the face of convincing scientific evidence of the urgent need for change, is anything but easy to generate, although the Paris Agreement at COP21 provides some evidence that policy makers may at last be taking the scientific evidence seriously. But in the absence of comparable evidence for the immediate need for radical increases in resource efficiency, and despite the evidence that many such increases could be economically and environmentally beneficial for society now, none of the concepts that have been created to promote resource efficiency seem to have the transformative power to significantly increase its rate of take-up. The uncertainties, policy makers' lack of willingness to intervene strongly in markets, and resistance lobbying from those who themselves as likely to be losers from attempts to promote resource efficiency, have to date been enough to prevent serious progress on this issue.

There are four possible outcomes to this situation, expressed here in terms of the analytical framework described earlier.

The first is that those advocating radical increases in resource efficiency (for example, those in Table 5) will be able to postulate a credible and plausible pathway for its achievement that allows it to be pursued at scale in practice. The second is that incremental changes (for example, those in Table 4) will be implemented in a way that opens up economic, social, political or technological space for such changes to be pursued more radically, or for more radical changes to be adopted. The third possible outcome is that real physical resource scarcity or scarcities, currently largely unforeseen, will arise, that will enforce radical increases in resource efficiency. A variant of this outcome is that, notwithstanding current successes in decoupling such impacts from resource use to some extent, the socio-environmental impacts of continuation of current trends in resource use (e.g. conflicts about mining and waste disposal; conflicts about water and land use etc.) become more and more unbearable, also leading to radical increases in resource efficiency. A fourth possible outcome is that approaches based largely on 'business-as-usual' will allow such scarcities as arise to be addressed within the current paradigm, such that radical change proves to be unnecessary.

The resource efficiency agenda is hence at a crossroads. In the domain of climate policy, policy makers increasingly reject outcome 4 in favor of some combination of outcomes 1 and 2, in view of compelling scientific evidence of dangerous outcomes in a business as usual scenario (outcome 3). Attitudes to policy making on resource efficiency are still largely based on outcome 4. This leaves only the hope that such attempts at outcomes 1 and 2 as actually occur may make more radical approaches more acceptable before outcome 3 causes the significant economic and social disruption that some now fear.

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Appendix A. Supplementary Data

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